Exact-finite-range DWBA analysis of 12C(6 Li, α)14N reaction at E(6Li) = 20 MeV

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EXACT-FINITE-RANGE DWBA ANALYSIS OF $^{12}C(^{6}\overrightarrow{Li}, \alpha)^{14}N$ REACTION AT $E(^{6}Li) = 20$ MeV

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Résumé. — Nous présentons une analyse DWBA des pouvoirs d'analyse observés dans la réaction $^{12}C(^{6}\overrightarrow{Li}, \alpha)^{14}N$ étudiée à Heidelberg à l'aide d'une source de $^{6}\overrightarrow{Li}$ vectoriellement polarisée. Nous avons concentré notre étude sur les trois états 1^+ de ^{14}N : fondamental, 6,20 MeV et 9,70 MeV, ceux-ci étant particulièrement aptes à une description en termes d'un transfert direct de deuton.

Abstract. — We have performed EFR-DWBA calculations of the analysing powers observed in the $^{12}C(^{6}\overrightarrow{Li}, \alpha)^{14}N$ reaction with the vector polarized $^{6}\overrightarrow{Li}$ source of Heidelberg. We have focused our analysis on the three 1^+ states : ground, 6.20 MeV and 9.70 MeV states of the ^{14}N nucleus which are particularly relevant for a deuteron cluster direct transfer.

Recently M. Makowska-Rzeszutko *et al.* (1) (see ref. [1]) have measured the analysing powers observed in the $^{12}C(^{6}\overrightarrow{Li}, \alpha)^{14}N$ reaction at $E(^{6}Li) = 20$ MeV using the vector polarized $^{6}\overrightarrow{Li}$ beam installed at the Heidelberg EN-Tandem [2]. Table I gives the transitions investigated by these authors and the dominant configurations of the ^{14}N residual nucleus states predicted by the shell model analysis of W. True [4]. Using these theoretical predictions and also the ^{14}N states already observed by K. Meier-Ewert *et al.* [5] we have focused our analysis on the three 1^+ states : g.s., 6.20 MeV and 9.70 MeV which are the most relevant for a deuteron-cluster direct transfer in a $(^{6}Li, \alpha)$ reaction. R. L. White *et al.* [6, 7] have already shown the evidence for the direct nature of this reaction at $E(^{6}Li) = 33$ MeV. In this way we have tried to analyse the analysing powers of M. Makowska-Rzeszutko *et al.* in the frame of the exact-finite-range distorted-wave-Born-approximation (EFR-DWBA) formalism developed by T. Tamura [10] which takes into account exactly the recoil and finite range effects. In this way we have modified the SATURN-MARS-1 Codes [11] of T. Tamura and K. S. Low in order to include the spin-orbit distortions in the optical waves and also to extract the polarization observables from the transition matrix. Table II gives the optical parameters we use in this work ; for the ^{6}Li channel we have two sets (denoted A and B) which are the result of a recent analysis we have made [8] of the $^{6}\overrightarrow{Li}$ elastic scattering

TABLE I

^{14}N excited states observed by M. Makowska-Rzeszutko et al. (1) *in the* $^{12}C(^{6}\overrightarrow{Li}, \alpha)^{14}N$ *reaction at* $E(^{6}Li) = 20$ MeV. *The dominant configurations are given by W. True* [2].

Energy (MeV)	J^π, T	Dominant configurations
—	—	—
0	$1^+, 0$	$p_{1/2}^2$
3.95	$1^+, 0$	core excited
4.91	$0^-, 0$	$p_{1/2}\,s_{1/2}$
5.11	$2^-, 0$	$p_{1/2}\,d_{5/2}$
5.69	$1^-, 0$	$p_{1/2}\,s_{1/2}$
5.83	$3^-, 0$	$p_{1/2}\,d_{5/2}$
6.20	$1^+, 0$	$s_{1/2}^2$
6.44	$3^+, 0$	$s_{1/2}\,d_{5/2}$
7.03	$2^+, 0$	core excited
7.97	$2^-, 0$	$p_{1/2}\,d_{3/2}$
8.49	(4^-)	—
8.96/8.98	$5^+/2^+$	unresolved
9.13	$2^+, 1$	core excited
9.39	2^-	—
9.70	$1^+, 0$	$d_{5/2}^2$
10.06/10.10	?	—
10.81	4^+	—

(1) MAKOWSKA-RZESZUTKO, M., EGELHOF, P., KASSEN, D., STEFFENS, E., WEISS, W., FICK, D., DREVES, W., KUBO, K.-I. and SUZUKI, T., private communication.

TABLE II

Optical parameters of the entrance and exit channels. All the depths are in MeV ; *the radii and the diffusenesses are in* fm. *The radii have the form* $R = r_0 A_T^{1/3}$

		V	r_0	a	W_{vol}	r_0	a	V_{LS}	r_0	a	r_{oc}
$^{6}Li + ^{12}C$	(A)	71.1	1.954	0.689	8.62	2.504	0.114	18.37	1.243	0.476	1.35
	(B)	71.1	1.954	0.689	8.62	2.504	0.114	14.62	1.476	0.293	1.35
$\alpha + ^{14}N$		54.87	1.748	0.569	5.17	1.748	0.569	—	—	—	1.2

of W. Weiss *et al.* [3] ; for the α channel we have used optical parameters at 19.2 MeV taken from C. M. Perey and F. G. Perey's table [9]. The cluster-direct-transfer calculations we have made assume that ^{14}N is a ^{12}C closed-shell core plus a bound deuteron. The deuteron is assumed to be in a 1S internal state and the α particle and deuteron in ^{6}Li have only 2S relative motion (the 1S relative state will be discussed later on). These bound state Woods-Saxon parameters and the cluster configurations, calculated from W. True [4] with the relation

$$\sum_{i=1}^{2} [2(n_i - 1) + l_i] = 2(N - 1) + L ,$$

are taken from R. L. White *et al.* [6, 7] and are given in the table III.

TABLE III

Bound state parameters and assumed cluster configurations. The energies are in MeV ; *the radii and the diffusenesses are in* fm. *The radii have the form* $R = r_0 A_T^{1/3}$.

			r_0	a	E_S	N	L
^{14}N	g.s.	1^+	1.94	0.65	10.27	1	2
	6.20 MeV	1^+	1.94	0.65	4.07	3	0
	9.70 MeV	1^+	1.94	0.65	0.57	2	2
^{6}Li	g.s.	1^+	2.15	0.65	1.47	2	0

Figure 1 displays the results we have obtained for the ^{14}N 1^+ states : g.s., 6.20 MeV and 9.70 MeV. The upper part of this figure shows the difference between two sets A and B of optical parameters for the entrance channel. Main difference concerns the analysing power of the $^{6}\overrightarrow{Li}$ scattering on ^{12}C which is described better with B than A set. This difference is weak for the 6.20 MeV state and quite large for ground state, the A-set giving the best result. We have also tried to assume a 1S state for the α-d relative motion in ^{6}Li. The results of these calculations are given on the lower part of the figure 1 and they confirm that the 2S relative motion for the ^{6}Li wave function seems to be more physical than the 1S one. Moreover such a 2S relative

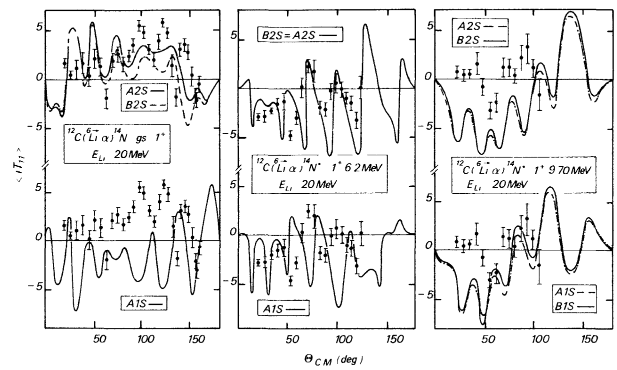

FIG. 1. — Angular distributions of analysing powers $\langle iT_{11} \rangle$ for the $^{12}C(^{6}\overrightarrow{Li}, \alpha)^{14}N$ reaction for the three ^{14}N 1^+ states : g.s. 6.20 MeV and 9.70 MeV. A (or B) denotes the ^{6}Li optical parameter set used while 2S (or 1S) denotes the relative motion state used for the description of $^{6}Li(\alpha + d)$.

state is predicted first by the shell-model and also when antisymmetrization is included in a ^{6}Li cluster model [12, 13]. The use of a 2S relative state is not confirmed by our results concerning the 1^+ 9.70 MeV state but it must be noted that the agreement between our calculation and the experimental data is not so good especially at forward angles.

Our EFR-DWBA analysis of the analysing powers observed in the $^{12}C(^{6}\overrightarrow{Li}, \alpha)^{14}N$ reaction at $E(^{6}Li)$ = 20 MeV gives a good justification of the description of this mechanism by a deuteron-cluster direct-transfer. The higher order terms seem here to be negligible, while at $E(^{6}Li)$ = 22.8 MeV we can observe a strong contribution of two-step process [14]. This is also the case in the $^{16}O(^{6}Li, \alpha)^{18}F$ reaction at $E(^{6}Li)$ = 34 MeV where the exchange effects seem to be important [15].

Further investigations concerning this $^{12}C(^{6}\overrightarrow{Li}, \alpha)^{14}N$ reaction at $E(^{6}Li)$ = 20 MeV are being carried out especially concerning the description of all transitions observed by M. Makowska-Rzeszutko *et al.* (1) in terms of a two-nucleon transfer treatment.

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